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ABSTRACT

The manual was developed as a reference for teaching students about transmissions in farm tractors. The manual is divided into five sections: (1) transmission history, (2) gears and bearings in transmission, (3) sliding-gear transmissions, (4) planetary gearing, and (5) glossary. The working principles of the sliding-gear transmission, the most extensively used transmission in farm tractors are described in detail. (VA)

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TRACTOR TRANSMISSIONS

(VT 102 062)

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Transmission History

SECTION 1

Gasoline and diesel engines differ from electric motors or steam engines in that they *can not develop full power at low speeds.* Both the electric motor and steam engine will start a vehicle moving from a dead stop by just applying power. The speed of the vehicle is controlled by the amount of power applied. A gasoline or diesel engine will stop if the RPM (revolutions per minute) are too low, so a method of disconnecting the engine from the driven part of the vehicle must be provided. Because of the low power provided by both at low RPM, a means must be supplied to give the engine a mechanical advantage in order to start a vehicle from a standstill. **The transmission,** in which gearing or some other method is used, *provides this mechanical advantage to the engine.*

One of the early attempts toward solving the transmission problem was the **friction transmission** (Figure 1). *This transmission provided for an infinite number of forward and reverse speeds.* The friction transmission had a driving disc which rotated at the same speed as the engine. The driven element—friction wheel—was a large fibre-faced wheel that was placed at right angles to the driving disc. It was on a splined shaft which in turn drove the rear axle through chains or belts.

The operator controlled the speed and direction by means of a lever which moved the friction disc back and forth on the splined shaft. *The friction disc could be placed near the center of the driving disc for power or away from the center for speed.* The farther from the center the higher the speed. *By moving the friction disc to the other side of the center, reverse was accomplished.*

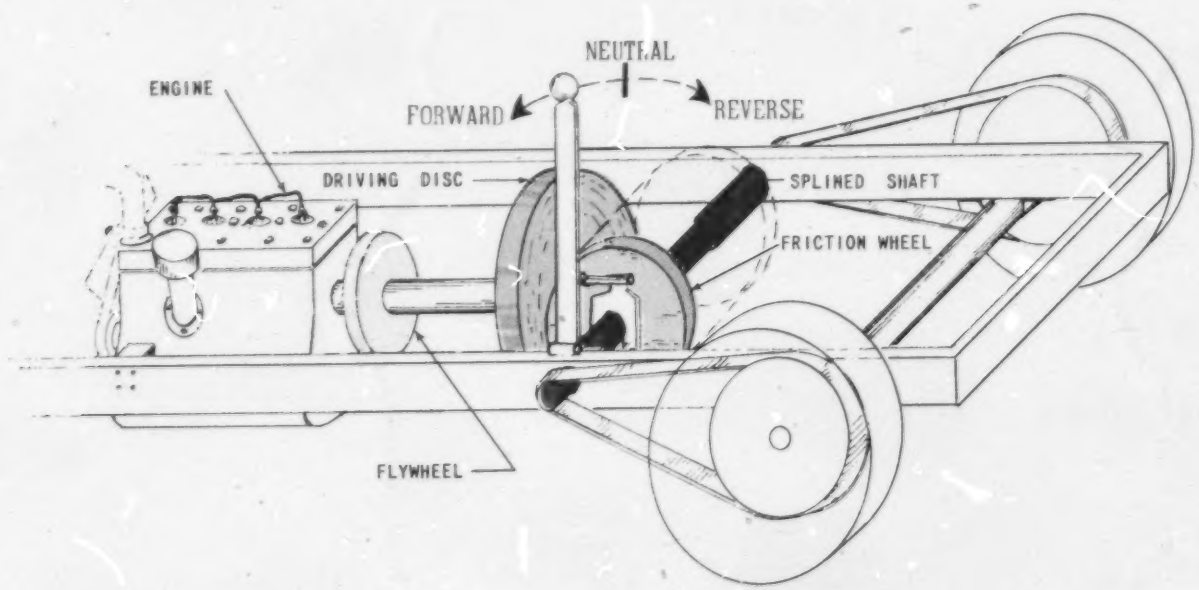


FIGURE 1. **Early transmissions were quite simple. The driving disc was connected directly to the engine. The friction wheel could be moved back and forth on the splined shaft. In position shown, near maximum speed is provided. If moved towards the center of the driving disc, speed becomes less and power increases. If moved past center to the other side, the vehicle is in reverse.**

The **friction transmission,** with its smooth change in speed ratio, infinite number of speeds, and simple construction, had **many disadvantages.** It was not a positive drive so there was much loss of power through slippage. Flat spots wore on the friction disc causing a bumping noise. These disadvantages, plus the fact that the friction disc had to be frequently replaced, caused the early abandoning of the friction transmission.

Early manufacturers tried to make a transmission that provided automatic or semi-automatic shifting and avoided the use of gears, but because of the weakness in the automatic applications, the manually-shifted gear transmission was destined to be used for many years.

The first big step in the development of a geared transmission was the introduction of the **sliding gear.** Emile Levassor, a Frenchman, originated the first sliding-gear transmission. It was ridiculed as being crude and impractical, but after gears had undergone a number of improvements, the sliding-gear transmission proved to be highly satisfactory. As improvements were made, sliding-gear transmissions became more widely used and, until the advent of the automatic and semi-automatic transmissions, was the most common form of transmission used.

TRANSMISSIONS IN FARM TRACTORS

A transmission, as used in a farm tractor, is a mechanical means of:

1. Transmitting power to the driven member of the machine.
2. Increasing or decreasing speed or power of the machine.
3. Controlling travel (forward or reverse) of the machine.

The three main transmissions now used in farm tractors are: (1) *the sliding gear,* (2) *sliding gear with synchronizer* and (3) *planetary geared.*

Transmissions on early tractors consisted of heavy, cast-iron, exposed gears. These transmissions were heavy, noisy, and wore out rapidly. They usually provided for only two speeds forward and a reverse.

As tractors became lighter and metalurgy improved, transmissions also became lighter and were improved. Some of the improvements incorporated are: (1) machined and hardened steel gears, providing more strength and less weight, (2) enclosure of gears in an oil-and-dust-tight housing, (3) anti-friction instead of plain bearings and bushings and (4) three to six or more forward speeds.

Gears And Bearings In Transmissions

SECTION 2

GEARING IN TRANSMISSIONS

An **ideal transmission** is one that has a so-called "infinitely-variable gear" in which the ratio of torque can be varied continuously within wide limits. This transmission would permit operating the engine at all times under the *most favorable conditions with respect to fuel consumption and wear*. However, only a relatively small number of ratios, or gear changes, can be provided in an ordinary geared transmission because they would make the gear too expensive and its operation too difficult. The desirable number of gear changes and their ratios depend on the use to which the transmission is to be applied.

Transmissions in wheel and crawler tractors are designed for power. Speed becomes a factor only in road gear on wheel tractors. Therefore the gear

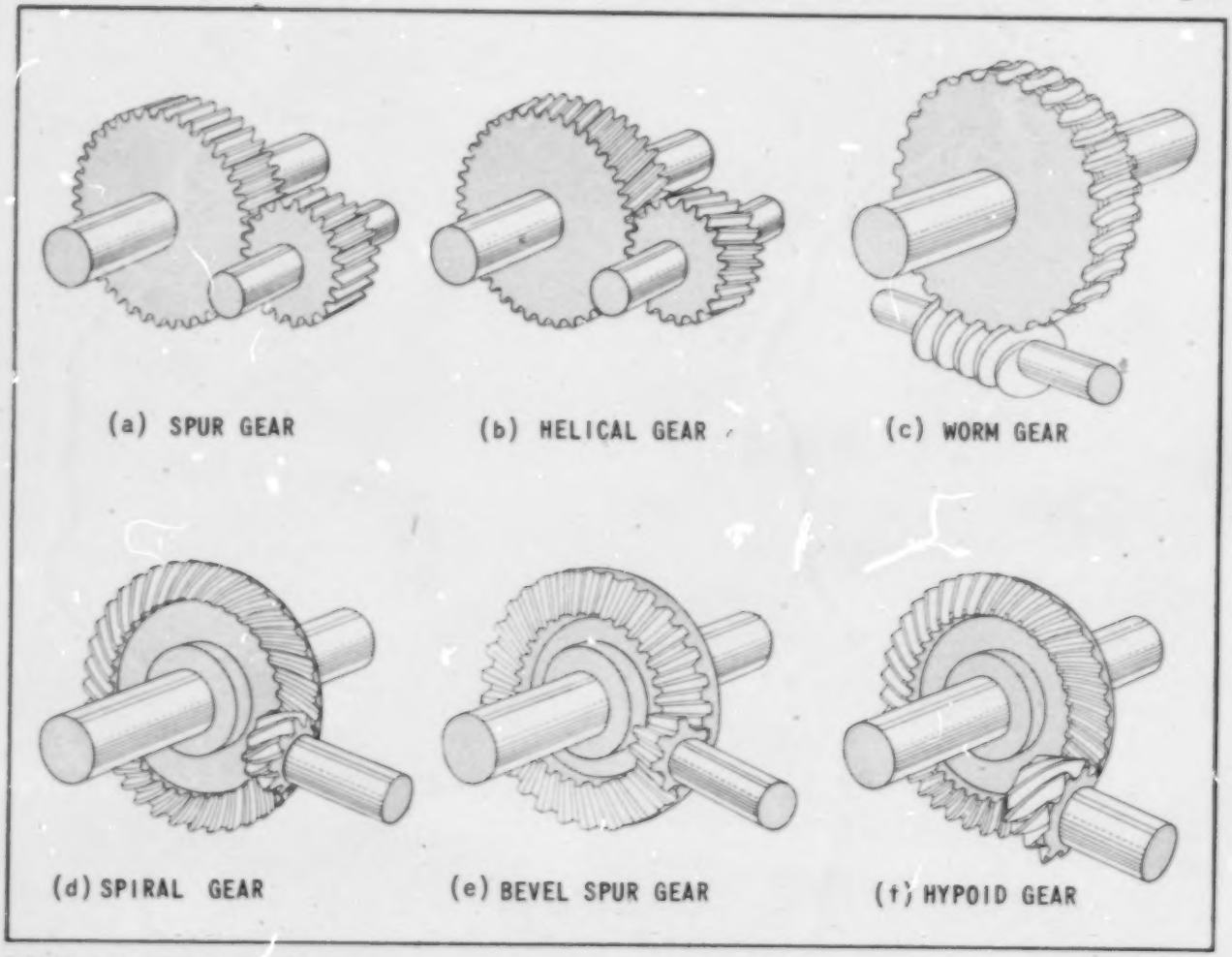


FIGURE 2. Common types of gears.

ratios in these transmissions will be low in relation to speed and high in relation to torque.

In tractor power units, **gears** *are used to transmit power from one shaft to another.* These shafts may operate in line with each other, parallel to each other, or at an angle to each other. The shafts in transmissions are usually mounted parallel.

In order to function properly, *meshing gears must have teeth of the same size and design.* It is also necessary to have *a minimum of two teeth engaged at all times.* Some tooth designs provide for contact between more than two teeth.

Gears are usually classified by the type of teeth used and the type of surface on which they are cut. *Worm, bevelspur, spiral, hypoid spur and helical* are the most common types of gears. In tractor transmissions, spur and helical types are commonly used. They are the only types discussed here.

Spur gears (Figure 2a) are cut on a cylinder and the teeth are straight and parallel to the axis. The spur gear is the simplest type of gear and most commonly used in transmissions. This type of gear *does not cause any end thrust* when it transmits power.

Helical gears (Figure 2b) have teeth that are cut according to a geometrical figure called a "helix." That is, the teeth are cut at an angle to the axis of the gear. Helical gears, when transmitting power, *produce an end thrust* along the shaft (Figure 5). That is, there is a force produced that tends to force the gears apart sidewise. If there are several helical gears on one shaft, it is possible to reduce this force by using a left-hand helical tooth on one gear and a right-hand helical tooth on the other. This way the end thrust of the one gear tends to offset the end thrust of the other.

It is more difficult to manufacture helical teeth than spur teeth, but helical teeth have the advantage of *quieter and smoother operation.* Another advantage is the fact that helical gears have *more tooth contact* than spur gears, therefore more teeth transmit the load.

Gear trains may be composed of three or more gears. A simple train has each of the gears supported on a shaft. A sliding-gear transmission (discussed in SECTION III) is an example of a simple gear train which provides for changing the gear ratio.

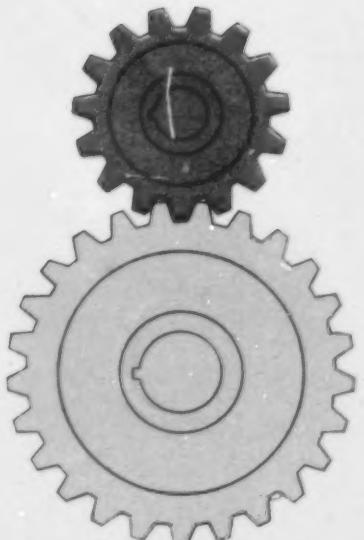


FIGURE 3. **Gear ratio is the number of teeth on one gear compared to the number of teeth on the second gear. The lower gear has 25 teeth. The upper gear has 15. The gear ratio is 25 to 15, but it is simpler to divide both numbers by 5 and express the gear ratio as 5 to 3 (5:3).**

Gear ratio is a method of expressing the speed and torque change that takes place in a gear train. The gear ratio between two gears is the ratio of the number of teeth on the large gear to the number of teeth on the small gear (Figure 3).

Automotive-type vehicles require different gear ratios to meet varying operating requirements. The two methods by which a change is made from one gear ratio to another in a simple gear train are: (1) constant-mesh shifting and (2) sliding-gear shifting. In both of these gearshift types it is necessary to momentarily interrupt the power that is transmitted in order to effect the shift. This is done by disengaging the clutch so the power train is disconnected from the engine.

ANTIFRICTION BEARINGS IN TRANSMISSIONS

Antifriction bearings are all fundamentally the same. They are made of: (a) *two hardened-steel rings called* **races,** which (b) have *steel balls, rollers, or needles* that roll between them. These are sometimes called "rolling elements." Most antifriction bearings have **separators** that space the balls or rollers uniformly around the bearing.

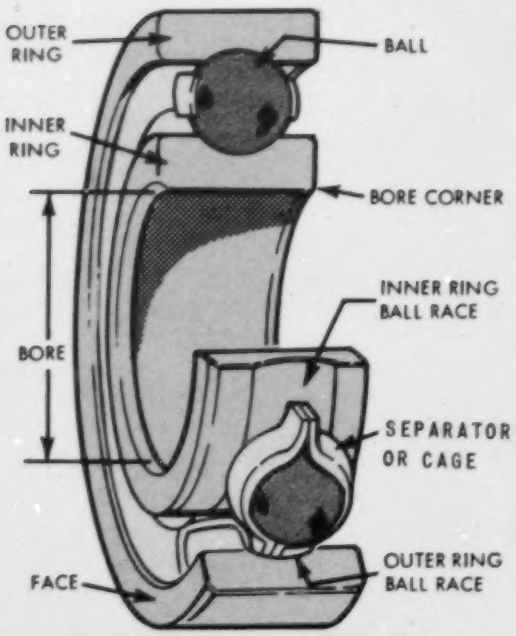


FIGURE 4. **Most antifriction bearings have an outer ring (race), an inner ring (race) and a separator.**

The *component parts of bearings* which provide rolling contact are: the *outer-ring*, the *inner-ring*, the *rolling elements*, and the *separator* (Figure 4). Some bearings are made without one of the rings — either the inner or outer ring is omitted. The rolling elements are then in direct contact with a hardened surface on the shaft or a hardened surface in the bearing housing. Others leave out the separators and allow the rolling elements to come into contact with each other.

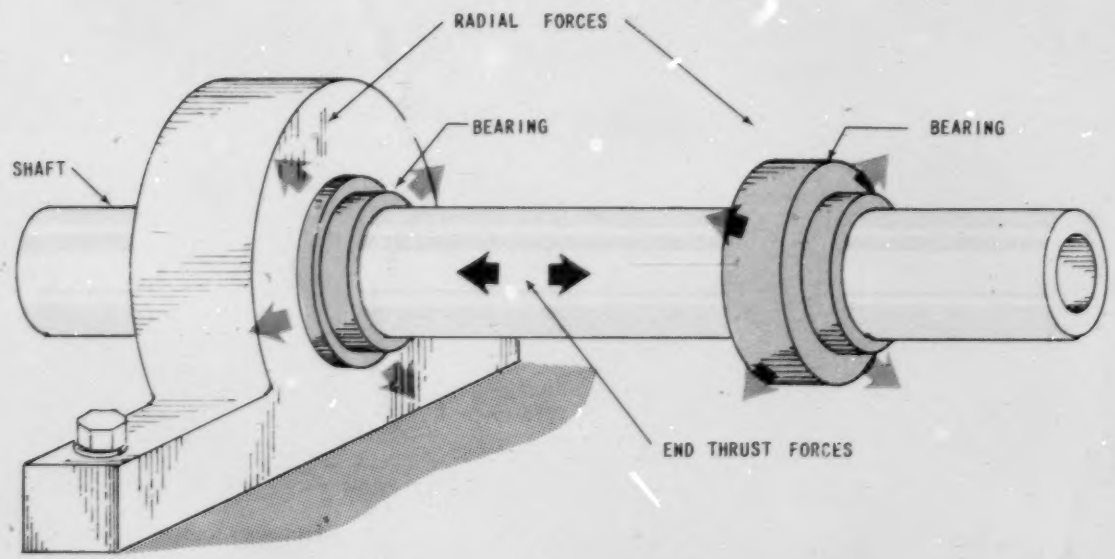
Needle bearings (Figure 10) do not require separators because of the close spacing of the needles. Frequently needle bearings use the shaft on which they are mounted for the inner ring or race.

The various uses of bearings require them to operate under many conditions. **Bearing loads** may be considered as two types: (1) *radial* and (2) *thrust* (Figure 5).

A *radial load* is defined as a force perpendicular to the axis of rotation.

A *thrust load* is defined as a force parallel to the axis of rotation. There are many cases where bearings must be able to carry both radial and thrust loads.

FIGURE 5. **Bearings may be subjected to either radial, or thrust forces, or both.**



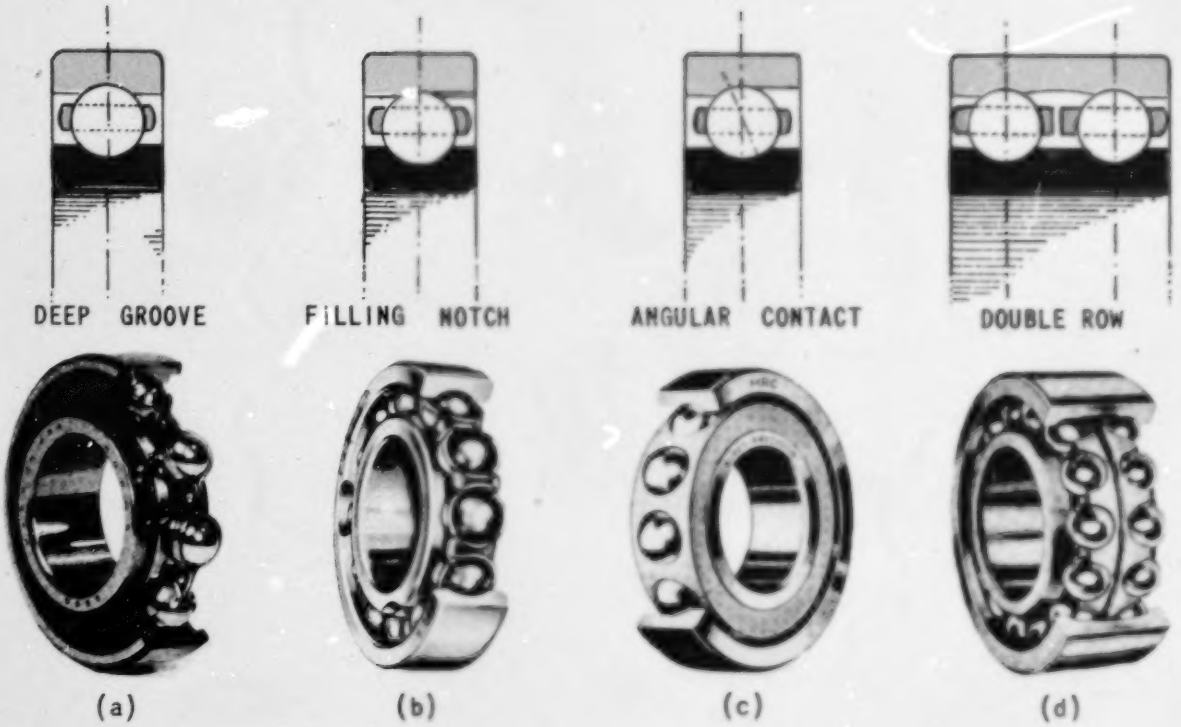


FIGURE 6. **Common types of ball bearings.**

Ball Bearings

Ball bearing types mostly originate from three basic designs. These are:

(1) Single-row radial

(2) Single-row angular contact

(3) Double-row angular contact

The **single-row deep-groove radial bearing** (Figure 6a) is the most widely used ball bearing and is employed in many modified forms. This bearing is capable of taking combined radial and thrust loads in which the thrust component is relatively high. However, this bearing is not self-aligning, therefore, an accurate alignment between the shaft and housing bore is necessary.

The **single-row deep-groove radial bearing with filling slot** (Figure 6b) is designed primarily to carry a radial load. This type of bearing, because it has a filling slot, has more balls inserted during assembly than the nonfilling-slot type. This type of bearing will take a certain amount of thrust in combination with a radial load. However, the use of this type of bearing is not advised where the thrust load exceeds 60% of the radial load.

The **single-row angular-contact type of bearing** (Figure 6c) is designed for a combined radial and thrust load where the thrust load may be large and radial deflection must be confined within close limits. This type provides a high shoulder on one side of the outer ring to take the thrust while the shoulder on the other side is only high enough to make the bearing non-separable. This bearing type is used either in pairs, or one at each end of the shaft, opposed, except where used for a pure thrust load in one direction.

Double-row ball bearings (Figure 6d) are, in effect, two single-row angular-contact bearings that are built as a unit. The internal fit between the ring and balls is fixed at the time of assembly and is not dependent upon mounting methods for internal rigidity. There is usually a known amount of internal pre-load built in for maximum resistance to deflection under combined loads with thrust from either end. With this built in pre-load, this bearing is very effective for radial loads where deflection must be minimized.

Other types of ball bearings are modifications of these basic types that provide arrangements for self sealing, location by snap ring, shielding, etc. The fundamentals of mounting remain the same.

One special type of ball bearing is the *separable magneto type* (Figure 7a). This bearing can be readily disassembled into its three major parts: inner-ring, outer-ring, and separator with balls. This bearing is suitable for a combination of radial and thrust loading but when used singularly can take thrust in only one direction. When used on both ends of the shaft, they can carry thrust in either direction. In any application the thrust capacity of the magneto-type bearing is not very high.

Another special type is the **self-aligning ball bearings** (Figure 7b). This bearing compensates for misalignment between shaft and housing due to shaft deflections, mounting inaccuracies, or other causes encountered. In *single-row bearings*, alignment is provided by a spherical outer surface on the outer-ring. In *double-row ball bearings* alignment is provided for by a spherical raceway on the outer-ring. The double-row bearing has considerable thrust capacity.

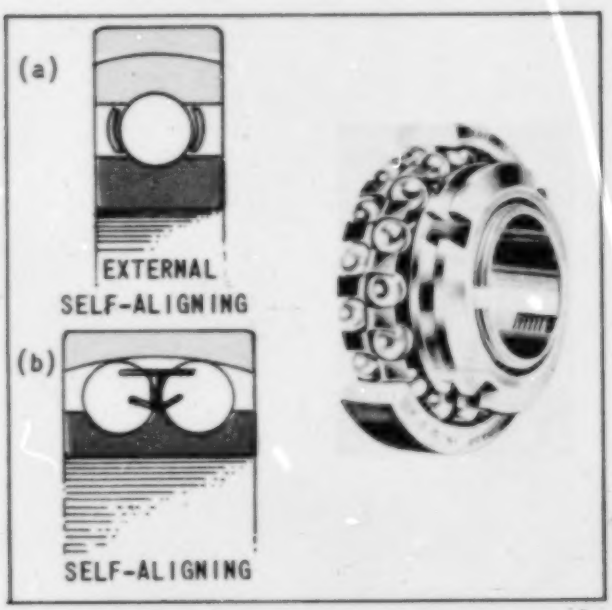


FIGURE 7. **Modified types of ball bearings.**

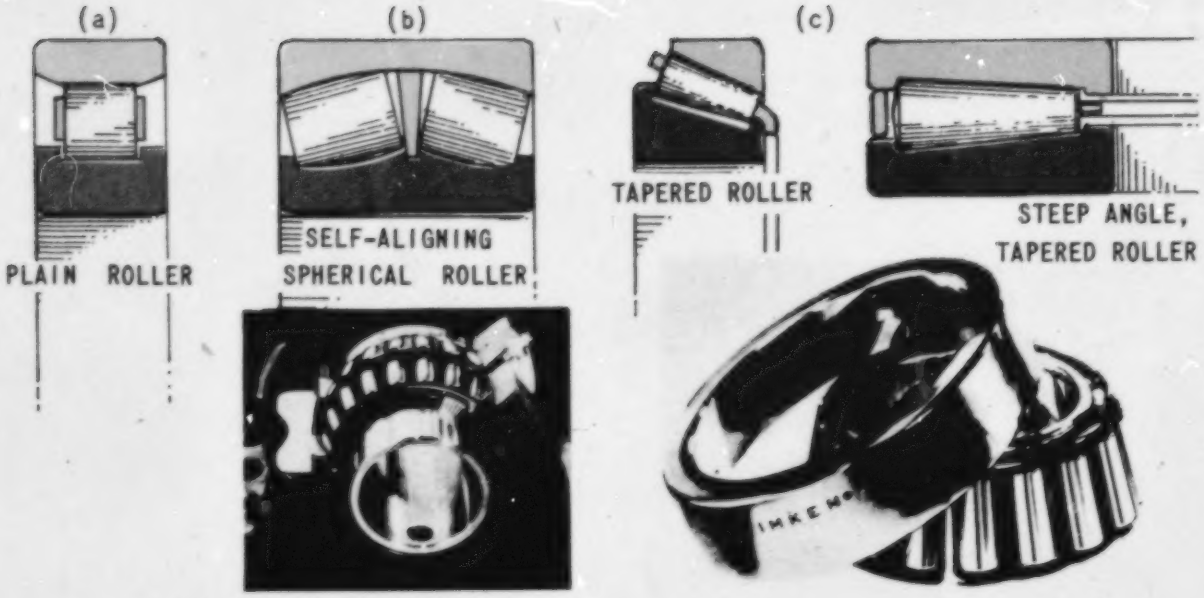


FIGURE 8. **Common types of roller bearings.**

Roller Bearings

Roller bearings are distinguished by the design of the rollers and raceways. They are *designed to take radial, combined radial and thrust, or thrust loads.* Roller bearings require almost perfect geometry of the raceways and rollers. Slight misalignment causes the rollers to skew and get out of line. For this reason retainers on roller bearings are heavier than on ball bearings.

Cylindrical or plain bearings (Figure 8a) have solid cylindrical rollers. If necessary, the shaft and housing can be used for raceways instead of separate inner and outer rings. This is important if radial space is limited. Low friction makes this type of bearing roller suitable for relatively high speed.

Spherical-rollers (Figure 8b) are usually furnished in double-row self-aligning mountings. The spherical outer raceway is common on both rows of rollers. The rollers are made barrel-shaped with one end smaller than the other. This provides a smaller thrust to keep the rollers in contact with the center guide flange.

A roller bearing with this type of roller has a capacity to take a high radial and thrust load and the ability to maintain this capacity under some degree of shaft and bearing housing misalignment.

Tapered roller bearings (Figure 8c) have rollers that are straight tapered and held in accurate alignment by means of a guide flange on the inner ring. These bearings are separable and have a high radial and thrust-carrying capacity.

Thrust Bearings

Thrust bearings are made in both ball and roller types. They are designed to take thrust loads alone or, in some cases, in combination with radial loads.

The **one-direction ball thrust bearing** (Figure 9a) consists of a shaft ring and a flat or spherical housing ring with a single row of balls between them. They are capable of carrying pure thrust loads in one direction, and cannot carry any radial load.

Two-direction ball thrust bearings consist of a shaft ring that has a ball groove in either side, two sets of balls, and two housing rings arranged so thrust loads in either direction can be supported. These bearings will not carry radial loads.

The **spherical-roller thrust bearing** (Figure 9b) is similar in design to the radial spherical roller bearing except that it has a larger contact angle. This bearing has barrel-shaped rollers with one end smaller than the other and can carry a very high thrust load. It can also carry radial loads.

Needle Bearings

Needle bearings have relatively small-size rollers, usually not more than $\frac{1}{4}$ inch in diameter, and have a relatively high ratio of length to diameter. This ratio usually ranges from 6 to 1 to 10 to 1. A feature that is characteristic of needle bearings, is the absence of a cage, or separator, for retaining individual rollers. Needle bearings may be divided into three classes:

(1) Loose-roller

(2) Outer race and retained roller

(3) Nonseparable units.

The **loose-roller needle bearing** has no integral races or retaining members. The needle rollers are located directly between the shaft and outer bearing bore. Usually the shaft and outer-bore bearing surfaces are hardened. Retaining members that have smooth unbroken surfaces are provided to prevent endwise movement. This type of bearing is compact and has a high radial load capacity.

The **outer-race and retained-roller type** of needle bearing comes in two types: (1) the drawn-shell and (2) the machined-race type. The *drawn-shell type* has needle rollers that are enclosed by a hardened shell that acts as a retaining member and as a hardened outer race (Figure 10). The needles roll directly on the shaft which should have its bearing surface hardened. The capacity for a given roller length and shaft diameter is about $\frac{2}{3}$ of the loose-roller type. This bearing is mounted in the housing with a press fit.

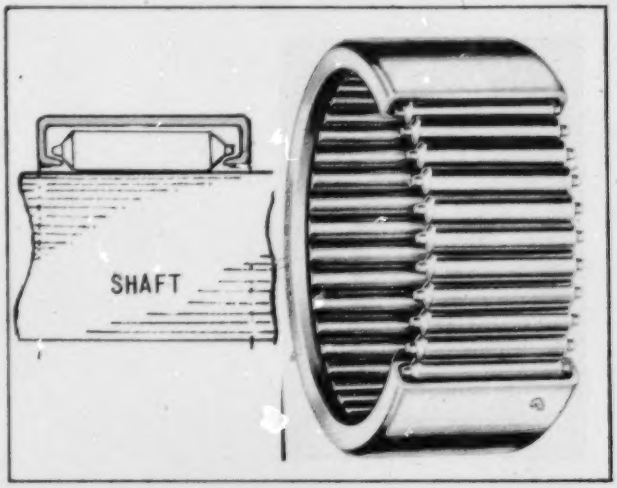
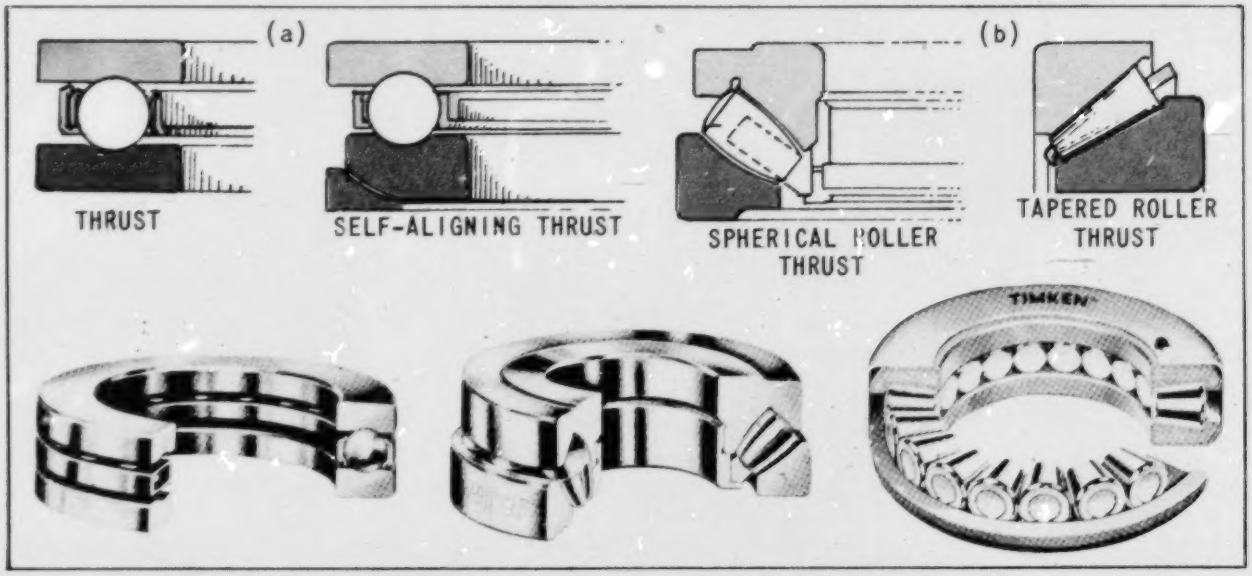


FIGURE 10. **One type of needle bearing.**

The **machined-race type** has an outer race that consists of a heavy machined member. Various modifications provide heavy ends, or faces, for end loca-

FIGURE 9. **Bearings designed for thrust in one direction may be either of the ball or roller type.**



tion of the needle rollers; or open-end construction with end washers for roller retention; or a cage which maintains roller alignment and is itself held in place by retaining rings. An outer member with a spherical seat, which holds the outer race, may be provided for self alignment. This type of bearing is applicable where split housings occur or a press fit is not possible.

The **nonseparable needle bearing** consists of an outer race, inner race and rollers. This bearing cannot be disassembled into its component parts. It is used where high static or oscillating motion loads are expected and where both inner and outer races are necessary.

Sliding-Gear Transmissions

SECTION 3

The *sliding-gear transmission* is the most extensively used transmission in farm tractors. Consequently, it is important to know how this type of transmission works. An explanation of a simple sliding-gear transmission that provides for three speeds forward and one reverse follows.

In Figure 11, the two gears that are used to change speed, or direction, are D and E. Both of these gears slide on the output shaft, but are splined to it so as to turn it.

When gear D is positioned to contact gear A — which is splined to, and stationary on, the input shaft — the transmission is in *first* or *low gear*.

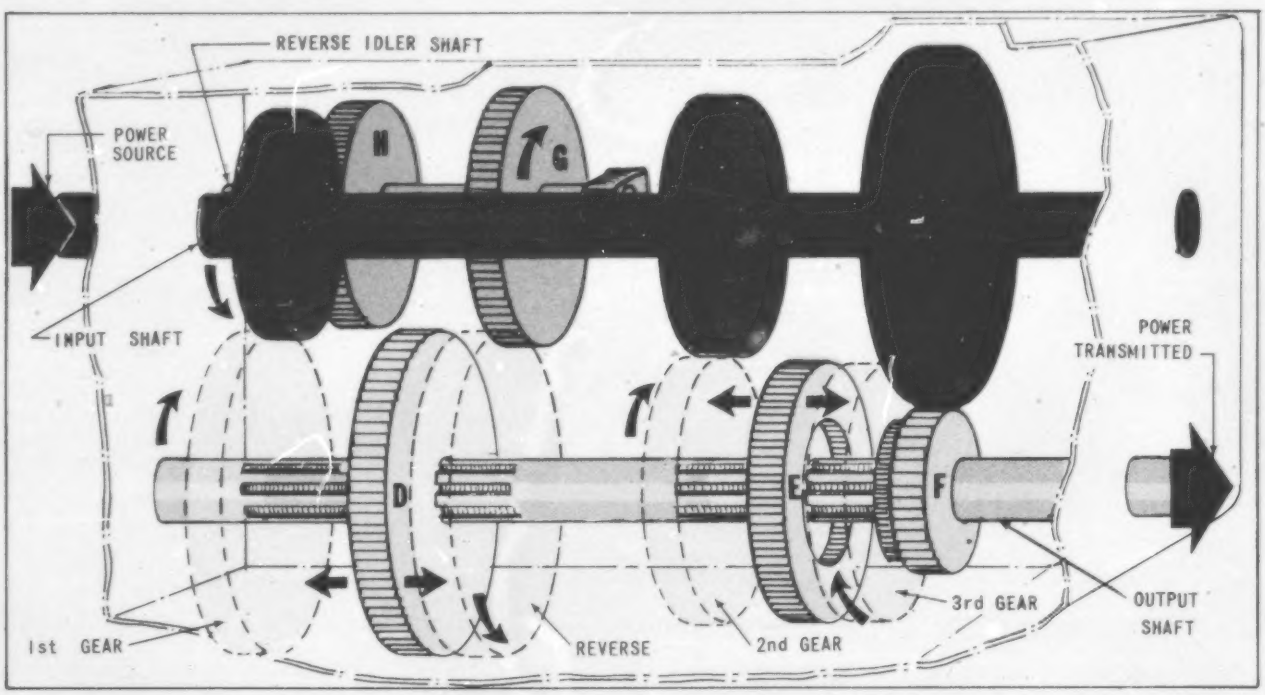
When gear D is positioned to contact gear G — which is stationary on, and splined to, the reverse idler shaft — the transmission is in *reverse*. Gear G is powered by gear H. Gear H is in constant mesh with gear A.

When gear E is positioned to contact gear B — which is splined to, and stationary on, its shaft — the transmission is in *second* or *intermediate gear*.

When gear E is engaged to gear F — which is not splined to the output shaft but which is constantly meshed to gear C — the transmission is in *third* or *high gear*.

If both gears, D and E, are positioned so as not to engage another gear, the transmission is in *neutral*.

FIGURE 11. **Principle of a sliding-gear transmission. Gears D and E slide on output shaft to provide 3 forward speeds and reverse.**



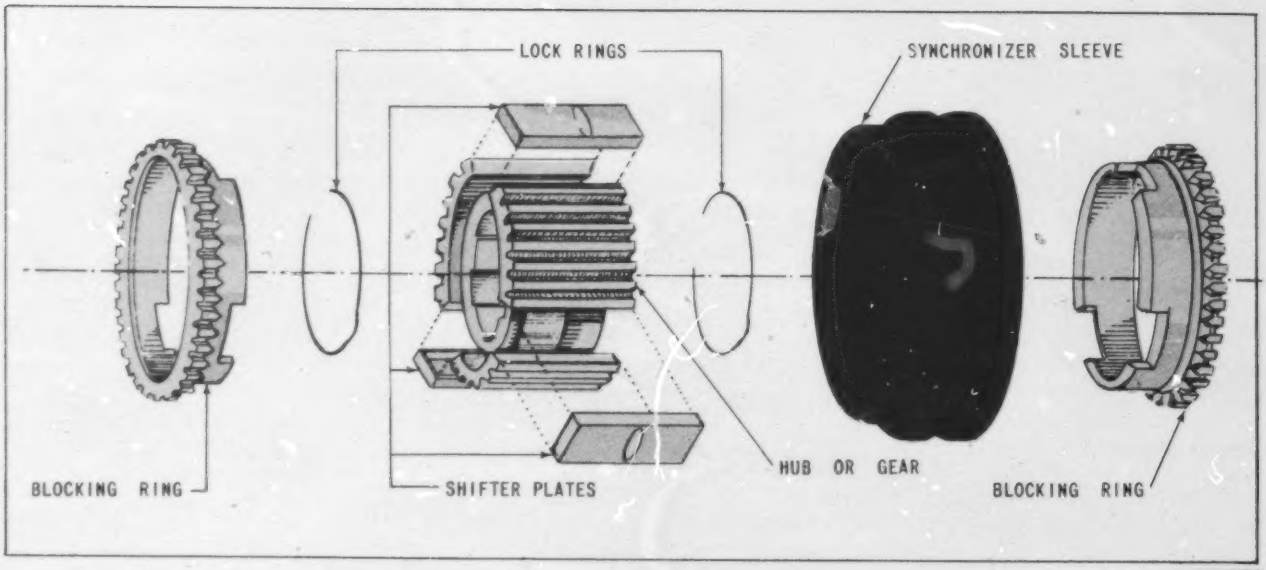


FIGURE 12. **Parts used in one type of synchronizer.**

The greatest difference between the transmission used in road vehicles and those used in tractors is that in tractor transmissions any of the gears, with the exception of the road gear, may be used over a long period of time under heavy loads. *Automobile transmissions would fail in a short time if run at full power in low gear for any length of time.* Auto transmissions provide for speed while tractor transmissions provide for power.

The **selection and design of a transmission** depends on the engine speed and speed of travel desired. Early tractors had only two or three speeds forward but, with the advent of rubber tires and improved engines, higher field and road speeds were possible. Transmissions became more complicated and provided for as many as twelve forward speeds and, also, incorporated a mechanism — a synchronizer — to *synchronize the shifted gears.*

SYNCHRONIZER — OPERATING PRINCIPLE

One type of synchronizer is known as the "*blocker type.*" The main components of this type of synchronizer are: the *blocking rings, lock rings, gear or hub, synchronizer sleeve and shifter plates* (Figure 12).

The **hub** is splined to the shaft on which the **synchronizer sleeve** is mounted. The sleeve rides in splines on the outside of the hub.

There are three **shifter plates** which ride in the slots of the hub. A rib in the top surface of each shifter plate rides in a circular groove in the hub. The two *lock rings* keep the plates in place against the sleeve.

There is a bronze **blocking ring** at each end of the clutch gear. The blocking rings each have three slots into which the ends of the shifter plates fit.

The inner surfaces of the blocking rings are cone-shaped and match the conical shape of the shoulders of the gears with which they make contact (Figure 13a). This inner surface has fine grooves cut into it. These grooves bring oil to the mating surfaces of the blocker and gear to prevent them from seizing, which would be caused by the friction created to synchronize the speed and directions of the components if no oil were present.

When making a shift, here is what happens:

1. The synchronizer sleeve is moved to the right (Figure 13a) towards the selected gear, carrying the shifter plates (inside the synchronizer sleeve) with it, and causing the right blocking ring to be pushed towards the gear.

2. The cone-shaped inner surface of the blocking ring contacts the cone-shaped shoulder of the gear to which it is to be meshed (see 13b), and rides up on the shoulder as the shifting motion continues.

   To prevent a complete meshing of the synchronizer-sleeve teeth with the teeth on the gear before synchronization occurs, the slots in the blocking ring are wider than the shifter plates which drive the blocking ring. This means that the blocking-ring teeth rotate slightly ahead of the teeth on the sleeve. It also means that the chamfered teeth on the blocking ring and the chamfered teeth on the sleeve are positioned so that the blocking ring prevents the clutch (synchronizer) sleeve from passing over the blocking ring and meshing with the gear.

3. The effort to complete the shift produces a drag which synchronizes the speed and direction of the gear and synchronizer.

4. When the gear and synchronizer are both rotating at the same speed and in the same direction, it is then safe to complete the manual shift without the gears clashing.

5. Another action then takes place. The blocking-ring teeth and the sleeve teeth are chamfered. After the gear slows down, the chamfer action of the sleeve teeth on the blocking-ring teeth forces the ring to a position where the sleeve teeth can pass through the ring teeth and mesh with the clutch teeth on the gear. When this happens, the shift is completed mechanically.

To summarize, the blocking ring drags hard on the shoulder of the gear in order to slow the gear down. The dragging action of the gear on the blocking ring makes the ring teeth meet with the sleeve teeth, preventing completion of the shift. When the gear has slowed down, so both gears rotate at the same speed and in the same direction, the chamfer action of the sleeve teeth on the ring teeth forces the ring into a position where complete meshing can take place.

By the use of synchronizers, the gears of a transmission can be in mesh at all times (Figure 14). The synchronizers are used to connect and disconnect the various gears from their shafts in order to direct the flow of power. Also, because the gears are in constant mesh, a gear that is stronger and more quiet in operation can be used.

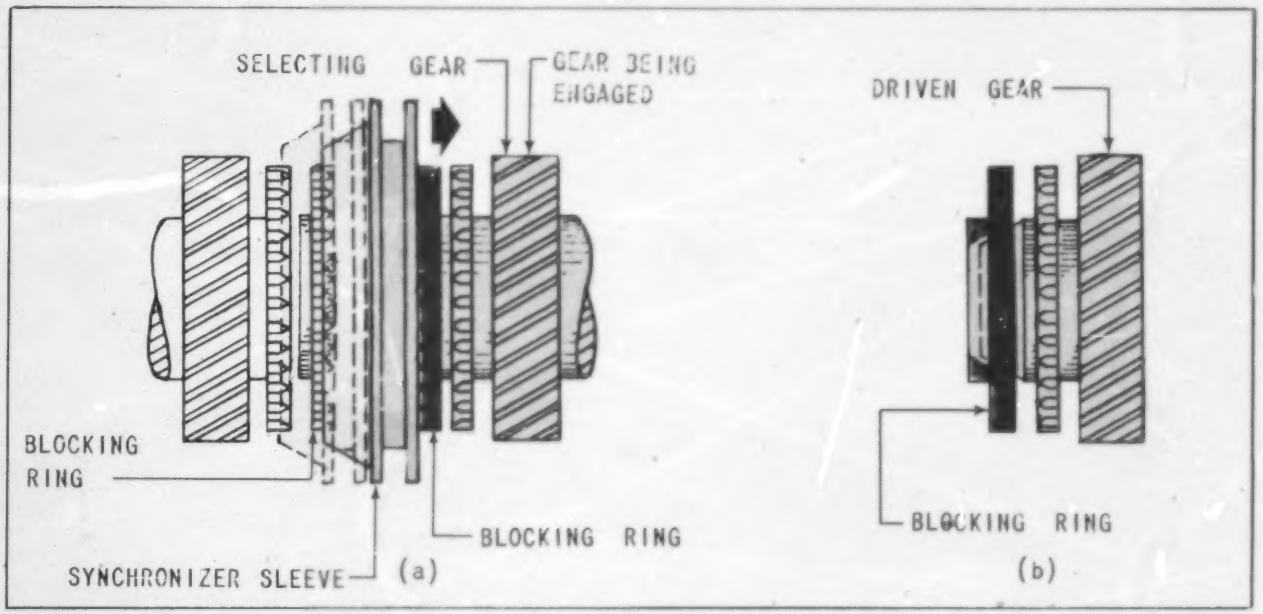


FIGURE 13. **How a synchronizer works when shifting gears. (a) The synchronizer sleeve is moved towards the gear with which it is to mesh. (b) Synchronization (matching the speed of the one gear to that of the other) is started when the cone-shaped inner surface of the blocking ring contacts the cone-shaped outer surface of the selected gear.**

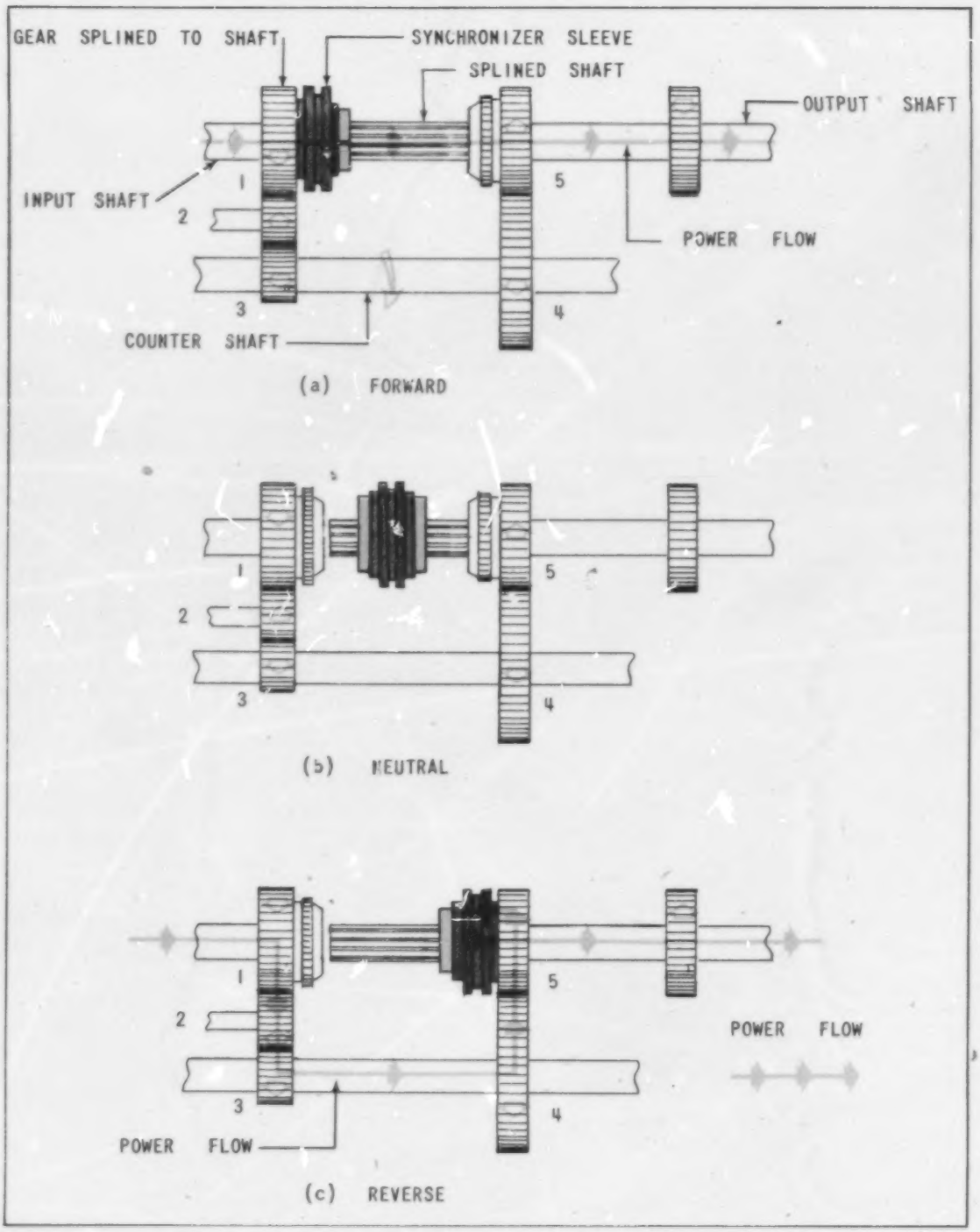


FIGURE 14. **How a synchronizer works in the transmission. In this transmission, the input shaft and synchronizer shaft are in line but are not directly connected. Gears 1, 2, 3, and 4 are each keyed to the shafts on which they are mounted. Gear 5 is not keyed to the shaft on which it rotates. (a) With synchronizer mated to gear 1, power is supplied directly to the output shaft. The counter shaft and all gears still rotate. (b) With the synchronizer centered — not attached to any gear — gears 1 through 5 rotate but no power is delivered. (c) With synchronizer mated to gear 5, rotation is reversed to the output shaft.**

Planetary Gearing

SECTION 4

Planetary transmissions were extensively used in early automobiles because they were of *simple design, easy to operate* and most important, they *could be constructed of common material* without expensive heat treating. Unlike other gearing, where only two or three teeth bear the load, the gears in a planetary system have the load divided equally among all of the gears — sun, planets and ring (Figure 15) — therefore, increasing the number of teeth bearing the load and decreasing the amount of load each tooth has to bear.

Besides decreasing the amount of load each tooth carries, the planetary system spreads the load evenly around the circumference of the system, thereby eliminating any sidewise stress on the axis of rotation which would tend to throw the shaft out of alignment — this is called "diametric loading."

In a planetary-geared transmission it is possible to effect a gear ratio change with a minimum interruption of the power flow. Also, it is possible to effect a gear reduction and have the input and output shafts rotating on the same axis. Planetary-geared transmissions can be designed to give both a large gear reduction and a large selection of gear ratios in a limited space.

Planetary gears are simple in design, but their operation is not well understood. Because of their extensive use, it is important to have a thorough understanding of the operation of a planetary gear in its simplest form before any understanding can be had of them in their more complicated forms.

PARTS OF A SIMPLE PLANETARY SYSTEM

The simple planetary gear set consists of four parts: (1) the *sun gear*, (2) the *planet gears* (there

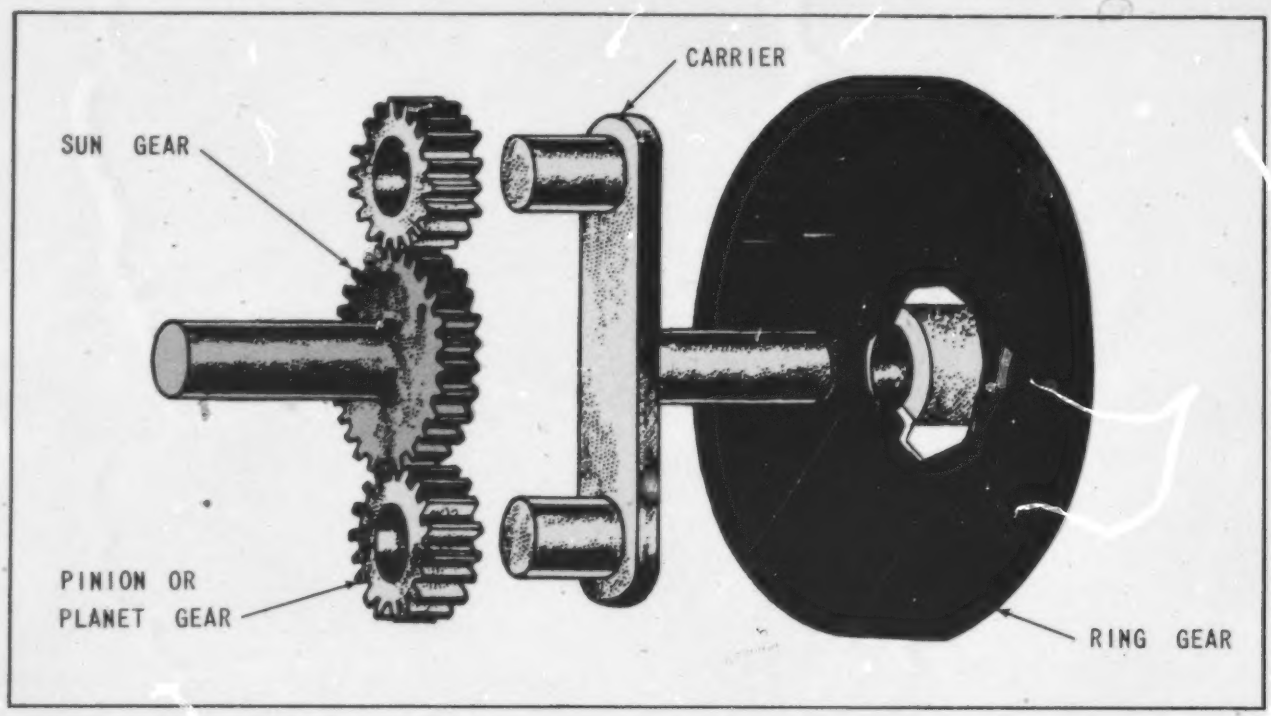


FIGURE 15. **Parts of a planetary transmission.**

may be 2, 3, 4, or 6), (3) the *carrier* and (4) the *ring gear* (Figure 15).

The **sun gear** is so named because it is the center of the system.

The **planet gears** are so called because they rotate around the sun gear in the same manner as planets rotate around the sun in the solar system.

The **carrier** is so named because the planet gears are attached to it and are carried around the sun gear by it. Since the carrier and planet gears rotate as one unit, they will be henceforth called the "carrier".

The **ring gear** is so named because it surrounds or rings the sun and planet gears.

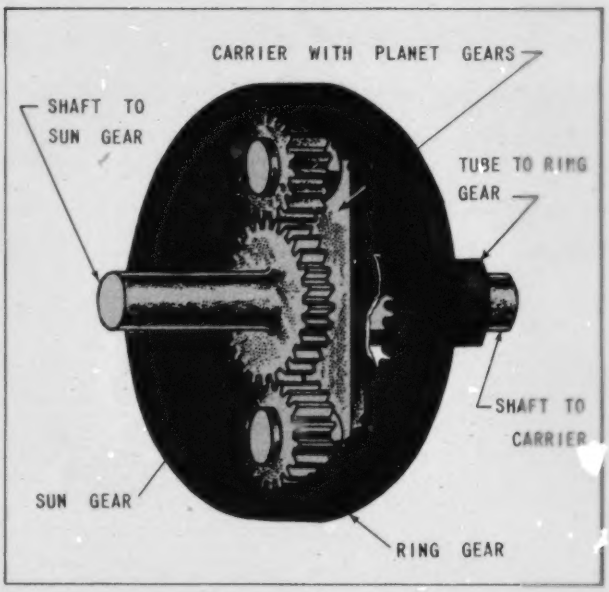


FIGURE 16. Planetary transmission with parts assembled.

POWER FLOW THROUGH A SIMPLE PLANETARY SYSTEM

When describing the action within a simple planetary system, the three basic components are called:

1. INPUT — the component through which torque comes into the gearing.
2. OUTPUT — the component through which torque, that has been applied to the gearing, is delivered out of the gearing.

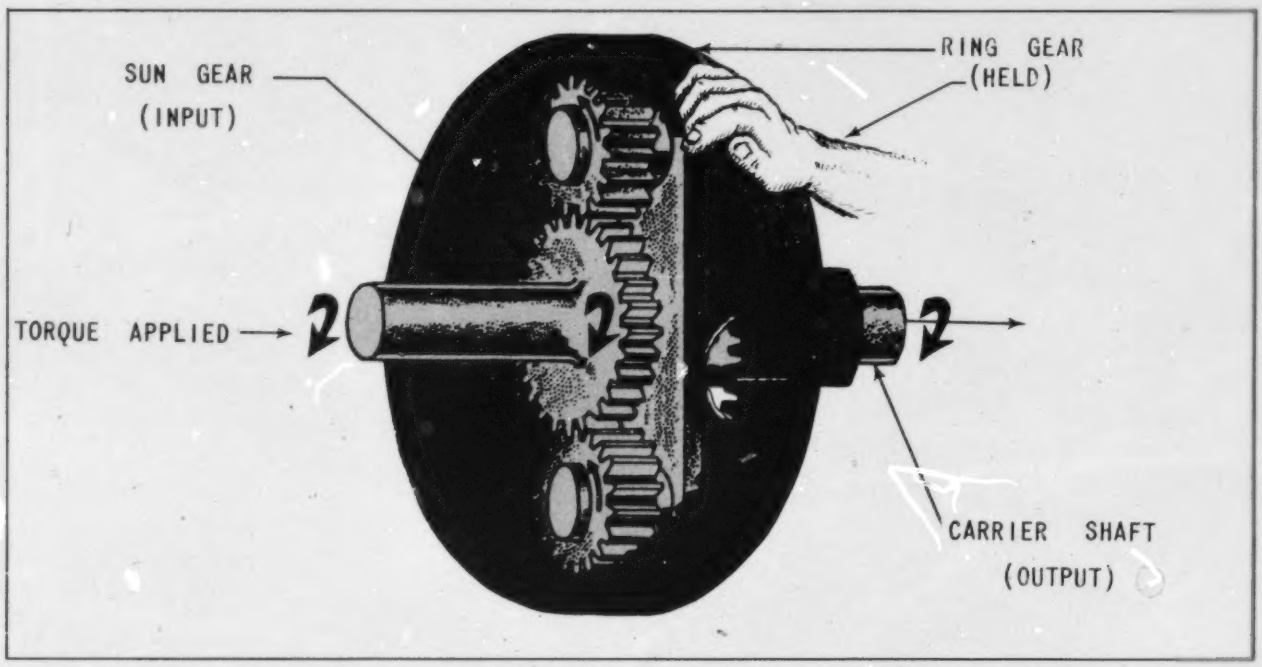


FIGURE 17. **If the ring gear is held, torque applied to the sun gear will cause it to rotate the planet gears. The planet gears "walk" around the ring gear. Since the planet gears are attached to the carrier, torque output is through the carrier shaft. Speed is decreased.**

3. HELD — the component which is held stationary and upon which the other components act.

There are many ways in which power can be transmitted through simple planetary gear sets. **The input, or engine shaft,** may be connected to drive the sun gear, the planet carrier, or the ring gear.

The **output shaft** can also be connected to any one of these units.

With the engine (or input) delivering power to one of these three units and the output connected to one of the members, there is one more condition that is necessary before power is transmitted — **one member must be held against rotation** to provide a basis for the other members to react upon.

For a clearer understanding of transmissions, using planetary gearing, it is necessary that the three basic actions of the carrier be understood.

THE FIRST BASIC ACTION described will be that in which the **carrier acts as the output member** (Figure 17.) **The ring gear is the held member.** Torque applied to the sun gear (input member) causes it to rotate and since the planet gears on the carrier are meshed to the sun gear, they rotate and "walk" around the stationary ring gear. This forces the carrier to rotate (output member).

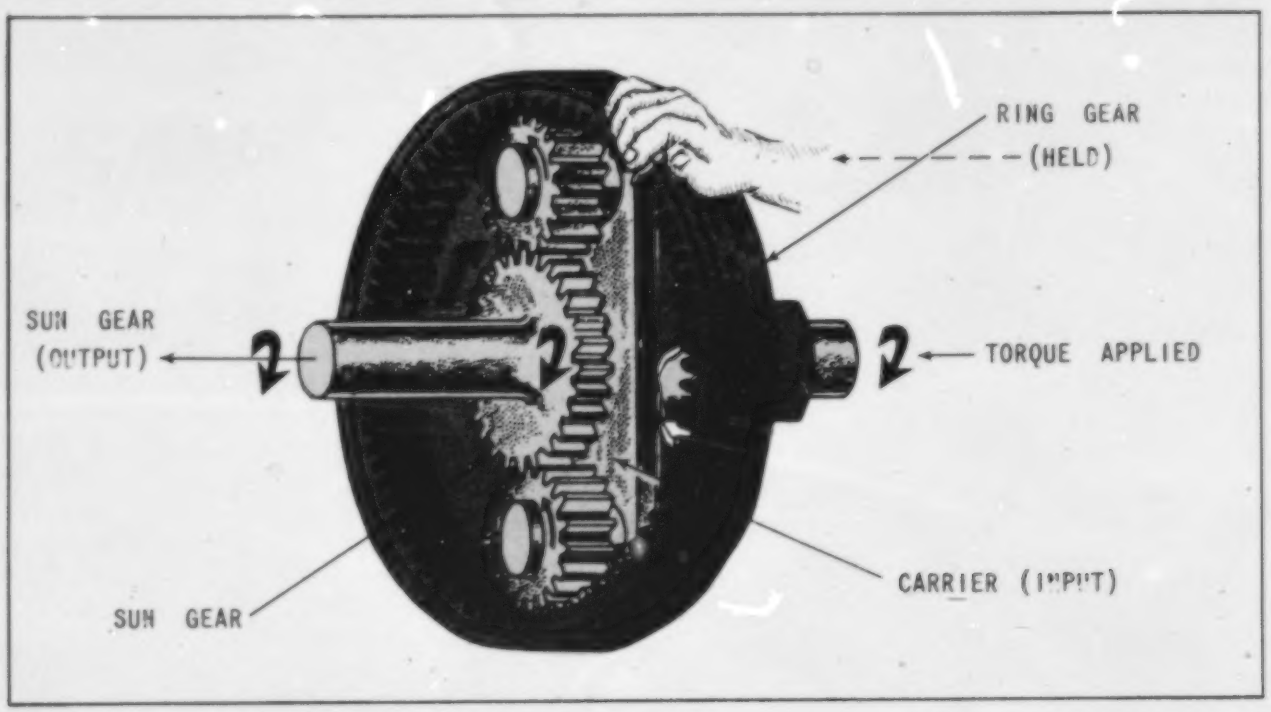
Under these conditions, the carrier is forced to rotate in the same direction as the sun gear but at a slower speed.

Thus, it can be seen that *when the carrier is the output member,* regardless of which other member is input or held, *there will always be a reduction in speed.*

THE SECOND BASIC ACTION will be that in which the **carrier acts as the input member** (Figure 18.) *With the ring gear as the held or stationary member,* the planet gears will "walk" around the ring and will turn in the opposite direction from that of the carrier, thereby causing the sun gear to rotate in the same direction the carrier is rotating but at a faster rate.

Thus, it can be seen that when the carrier is the input member, regardless of which other member is output or held, there will be an increase in speed.

FIGURE 18. **If the ring gear is held and torque applied through the carrier, the planet gears will "walk" around the ring gear and rotate the sun gear. Torque output is through the sun-gear shaft. There is an increase in speed.**



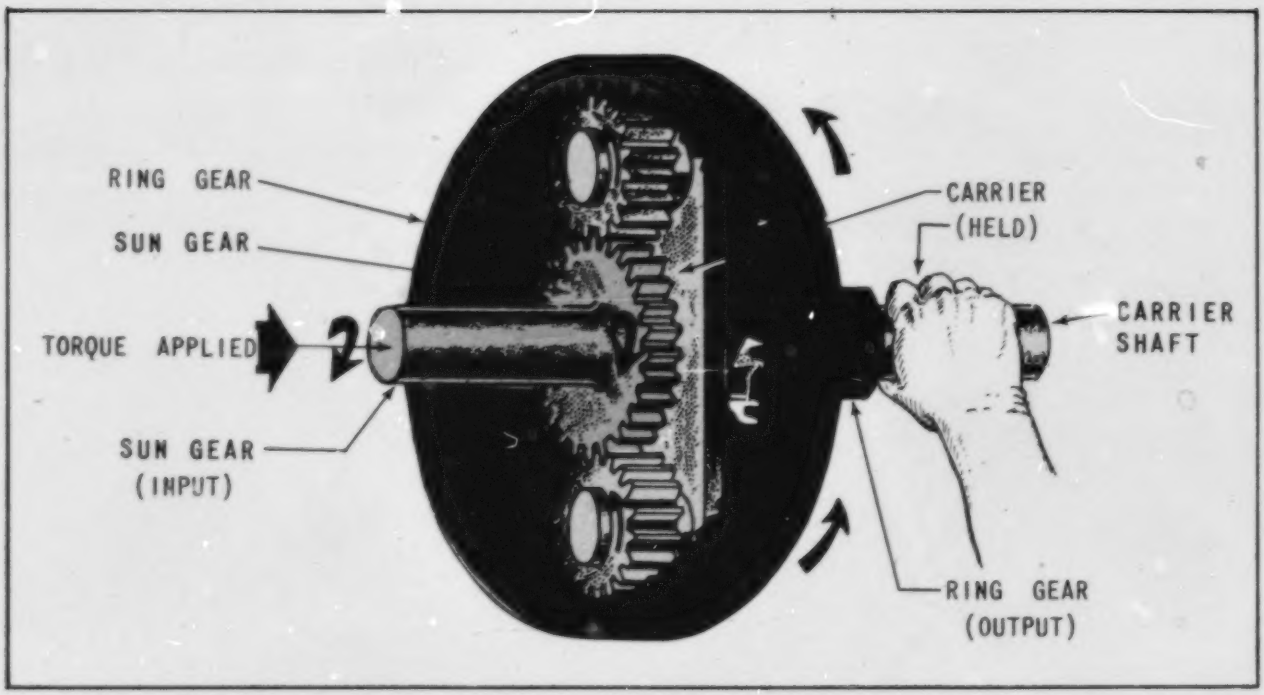


FIGURE 19. **If the carrier is held, the planet gears cannot move around the sun gear, but each is free to rotate on its own shaft. Consequently, if torque is applied to the sun gear, the planet gears rotate in the opposite direction. This causes the ring gear to rotate in the opposite direction.**

THE THIRD BASIC ACTION is that in which the **carrier is the held member** (Figure 19). With the carrier as the held (stationary) member, the planet gears rotate in the opposite direction as the input member thereby causing the output member to rotate in the opposite direction.

Thus, it can be seen that *when the carrier is the held member*, regardless of which other member is input or output, *a reverse action will result.*

Also, *if any two of the members are fastened together* by some means, the *entire unit will rotate as one solid unit*, regardless of which member is input or output because there is no chance for either the sun gear, planet gear or ring gear to rotate on one another.

In summarizing the methods of power transmission through a planetary system there are three things that must be considered. They are:

1. The three basic components of a planetary system.
2. The three results obtained from a planetary system.
3. The three controlling factors determined by the function (attitude) assigned to the carrier — that is, whether it is used for power input, power output or is held so it can not rotate.

The **three basic components** of the planetary system are the previously mentioned *ring gear*, *sun gear* and *carrier* (Figure 16). The functions of these three components will be discussed later.

The **three results in power transmission** through a planetary system are as follows:

1. *A reduction in speed* from the input member to the output.
2. *An increase in speed* from the input member to the output.
3. A reversal of input, — that is the *output member rotates in an opposite direction from the input member.*

When considering the **three controlling factors** of the carrier, it must be remembered that the end result from input to output depends upon how the carrier is used. The three carrier functions and their results are as follows:

1. When power is applied to the CARRIER it functions as the **input member** of the planetary system. There will always be an *increase in speed* from input to output.
2. When power is being delivered from the CARRIER, it functions as the **output member** of the planetary system. There will always be *reduction in speed* from input to output.
3. When rotation is stopped, the CARRIER functions as the **held member.** There will always be a *reversal of rotation* from input to output.

From this, it can be seen that the carrier controls the action of the planetary. Therefore, the following rule can be used when considering what to expect from a planetary system.

Carrier input equals speed increase. Carrier output equals speed reduction. Carrier held equals reverse.

If at **any time two of the members within the planetary system are locked,** or fastened together, the *entire system will rotate as one solid unit* and the result will be direct drive.

With the various combinations that have been mentioned, it can readily be seen that the planetary system can be easily adapted to many applications.

VECTOR METHOD OF CHECKING A SIMPLE PLANETARY

The vector method is another means for proving the basic rules of simple planetaries. It is also an easy method for checking out a simple planetary. *By the use of the vector method, the direction and speed of rotation of the output member, compared to the direction and speed of rotation of the input member, can be found.*

This method uses what is called a "vector base line" (Figure 20), which is obtained by drawing a line which represents the distance from the center of the sun gear (S) to the center of the planet gear (C), which is also the carrier path. A dot is put on the line at each one of the centers.

The line is extended to represent the distance from the center of the planet gear (C) to the tooth-contact point of the planet gear with the ring gear (R). Another dot is placed on the line at this point also.

This line, with the dots representing the three points, is a true representation of the distances in a simple planetary system.

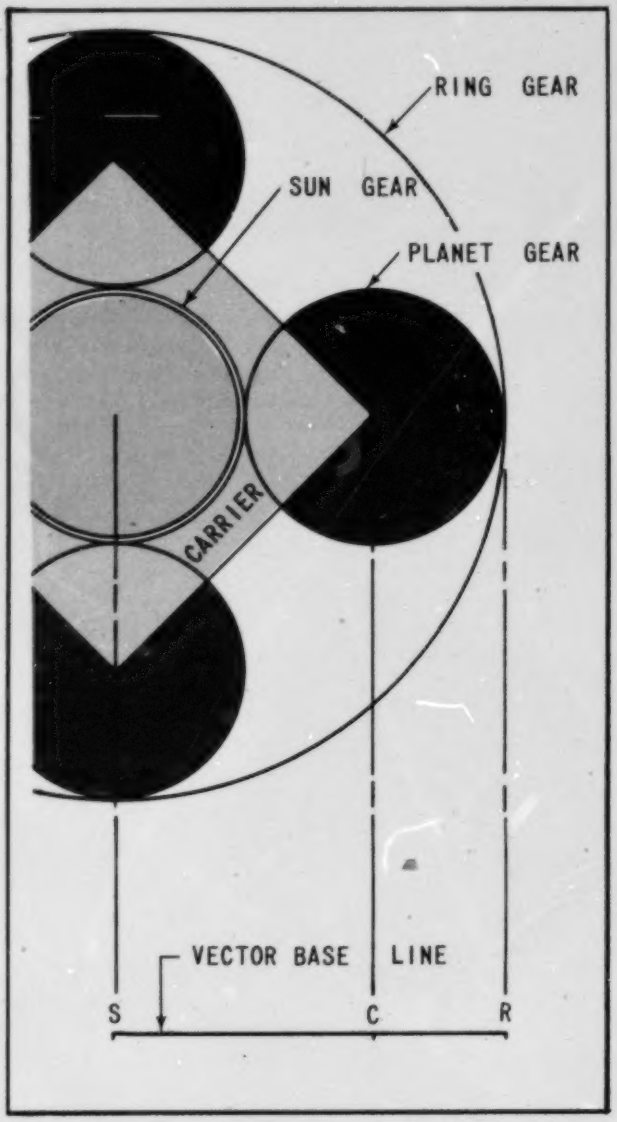


FIGURE 20. **Vector method of determining direction and speed of rotation of output member compared to the direction and speed of rotation of the input member. Base-line points represent distance between center of sun gear and center of planet gear, and distance from center of planet gear to tooth-contact point with the ring gear.**

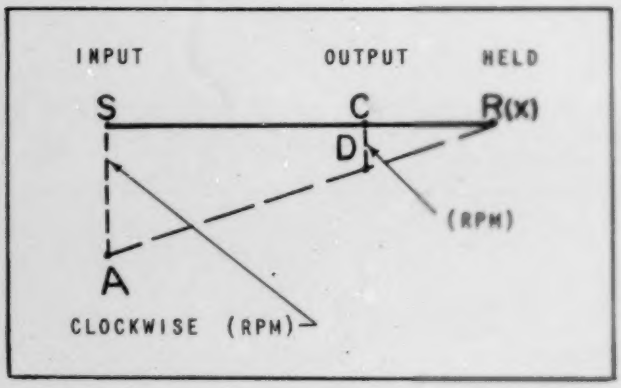


FIGURE 21. **The symbol "x" marks the held member. The length of the lines drawn below the vector base line is proportional to the speed of that member. For clockwise rotation, line is drawn below the base line.**

For the purpose of diagnosis and estimation of ratios, a vector base line is divided on a two-thirds, one-third basis. In other words, if the line is three inches long (S to R), the center of the planet gear will be two inches from the center of the sun gear (S to C), and the ring-gear contact point will be one inch from the planet-gear center (C to R). It must be remembered that this representation will give only an approximate ratio of input to output. For exact ratios, the exact distances must be obtained.

Now to determine the ratio and direction of output in relation to input, a vertical line is drawn from the input member. A certain length is to equal a given RPM, such as ½" equals 500 RPM, etc. This line, when drawn below the vector base line, represents *clockwise rotation* (Figure 21), when drawn above, it represents *counterclockwise rotation.*

Mark an X at the held member. The end of the line representing the INPUT is then connected with the spot (X) representing the HELD member. If necessary, this line is extended so as to be able to draw a vertical line from the OUTPUT to it.

The direction of output will depend on whether this vertical line is above or below the vector base line. The OUTPUT RPM can be obtained by just measuring the length of the vertical line representing output and converting inches to RPM.

In Figure 21, the *carrier* (C) is the OUTPUT member, the *sun gear* (S) is the INPUT member and the *ring gear* (R) is the HELD member. The base line is laid out and ¼" = 500 RPM.

The problem is to *find the direction and speed of the output member* (*carrier*). A line is drawn from the sun gear (S) down ¾". This represents 1500 RPM. With the held member marked X, a line is drawn from the end (A) of the line representing the input to the held member (X). A vertical line (D) is then drawn from the output member (carrier in this case) to the line (AX).

Now, the first thing that can be seen is that the *output rotation is in the same direction as the input,* but it is also necessary to know what the RPM of the output is. This is found by measuring the length of the line representing the output, which in this case is ¼" long. Therefore, because the representation of ¼" equals 500 RPM, it can be seen that the *output* (*carrier*) *speed is 500 RPM.*

Therefore, by using the vector method, it is proved that a reduction in speed is the result when the carrier is the output member.

In Figure 22, the input is the same, 1500 RPM, but now the *carrier* is the INPUT member, the *ring gear* is the HELD member and the *sun gear* is OUTPUT. The problem is to find the direction and RPM of the output.

First, a line is drawn from the carrier (C) down ¾" which represents 1500 RPM. The end of this line is marked A. This point (A) is connected with the held member which has been marked (X). This line

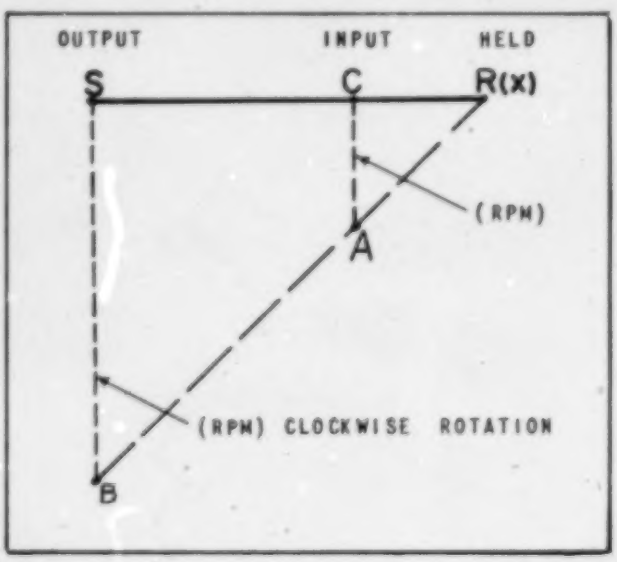


FIGURE 22.

is extended so as to be able to connect a vertical line from the output member (S). A vertical line is drawn from (S) to point (B). By observation, it can be seen that the output rotation is the same as the input because both lines are below the vector base line.

Now to determine the output RPM, the length of the output line is measured. This length is found to be $2\frac{1}{4}$" or 9/4". Because it was previously established that $\frac{1}{4}$" equals 500 RPM, it can be concluded that this output is 9 times 500 or 4500 RPM.

Therefore, by the use of the vector method, it has been proved that when the carrier is the input member, the result is an increase in speed.

In Figure 23, the carrier is the HELD member. The input RPM is the same — 1500 RPM. The problem is to find the direction and speed of rotation of the output member.

First, a $\frac{3}{4}$" line (representing 1500 RPM input) is drawn below the base line and vertical to (S) (the input member). The end of this line is marked (A). The held member (carrier) is marked with an (X), and (A) is connected with (X). This line is extended beyond (X) so as to be able to draw a vertical line from the output member (R) (the ring gear). The point of contact is marked (D). By observation, it can be seen that the line RD is above the vector base so the conclusion is that the direction of rotation of the output member is in a counterclockwise direction, which is the opposite of the input, thus giving a reverse in action.

To find speed of rotation, the line RD is measured and found to be $\frac{3}{8}$" long. It has been established that

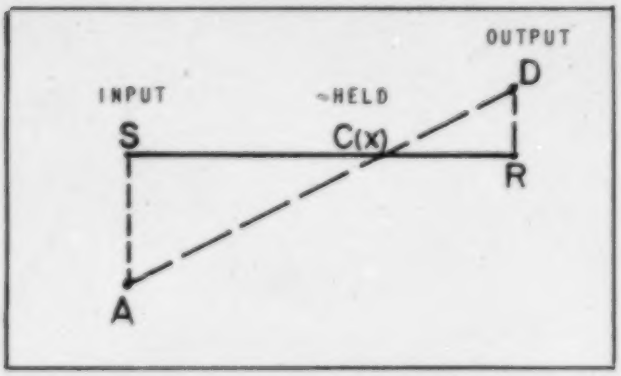


FIGURE 23. **When one, or both, vertical lines extend above the vector base line, this indicates counterclockwise rotation.**

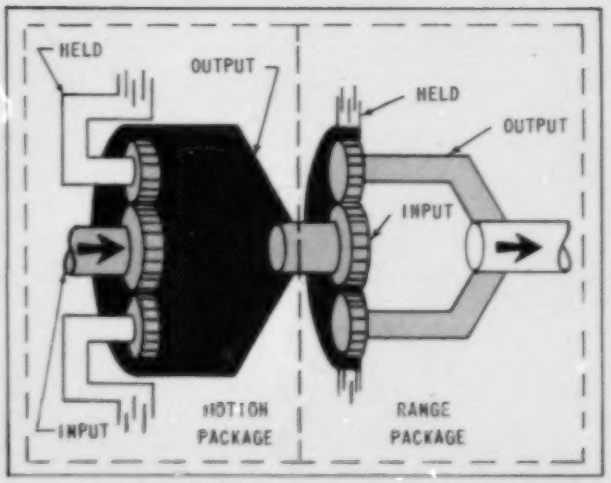


FIGURE 24. **Planetary units can be connected together to provide a selection of increases and decreases in speed as well as rotation change if needed.**

$\frac{1}{4}$" equals 500 RPM, so $\frac{3}{8}$", which is $1\frac{1}{2}$ times $\frac{1}{4}$, is converted to RPM — $1\frac{1}{2}$ times 500 equals 750. Therefore, in this illustration, there is 750 RPM in a reverse direction.

Therefore, by using the vector method, it is proved that when the carrier is held the result is a reverse of input.

Both types of illustrations, planetary gearing and vector method, prove the basic rule — whatever happens to the carrier determines the output of a simple planetary system. If the carrier is the input member, there is an increase in speed, if the carrier is the output member, there is a reduction in speed and if the carrier is the held member, there is a reverse in action. If two members are locked together, the RPM and direction is the same as the input.

Simple planetary systems can be combined or connected by various means to obtain a desired ratio.

The *combining of simple planetaries is referred to as* "simple planetaries compounded." To combine two simple planetary systems, the output member of the first system is connected to the input member of the second. Thus, it can be seen that many ratios can be obtained.

COMBINED SIMPLE PLANETARY SYSTEMS

In Figure 24, the first planetary system (motion package) has the sun gear as the input member, the

carrier as the held member and the ring gear as the output member. From the previous discussion, it is known that *the result will be a reversal of the output in the 1st planetary.*

The ring gear continues on to become the sun gear of the second planetary (range package), the planet carrier is the output member and the ring gear is the held or stationary member. Here, a speed reduction is accomplished; so from engine output there is a reversal in the first planetary system, then this reversal is reduced in the second. Therefore *low and reverse is accomplished.*

This is only one illustration of the many combinations that can be made. In the first system any member can be the input component, and any member the output component.

In like manner any member of the first system can be connected to any one of the members of the second system making it the input member. The output then can be taken from either of the other two members.

By **combining simple planetary systems** and selecting different components in each as input, output and held (or stationary) members, the *results can be numerous — ranging from a large reduction in speed to a large increase in speed or reverse action.*

Thus by compounding simple planetary systems it is possible to obtain a transmission that will give a number of gear ratios. By connecting the output member of one to the input member of another, it is possible to have three speeds forward and three speeds in reverse.

Because this type of transmission can be contained in a very small package, it is desirable for many applications, however, *this transmission is subjected to greater frictional loss than in spur-gear transmissions.*

Glossary

SECTION 5

ANTI-FRICTION BEARINGS - A class of bearings in which the main load is transferred through elements in rolling contact rather than sliding contact.

AUTOMATIC TRANSMISSION - A transmission in which gear or ratio changes are self-activated.

BEVEL SPUR GEAR - Gear that has teeth with a straight center-line that are cut on a cone.

CARRIER - The planet gears are attached to the carrier which in turn carries these gears around the sun gear.

CHAMFER - The surface formed by cutting away the angle formed by two faces of a piece of metal.

CONSTANT-MESH TRANSMISSION - A transmission in which the gears are engaged at all times.

COUNTERSHAFT - An intermediate shaft which receives motion from a mainshaft and transmits it to a working part.

GEAR - Gears are machined wheels that transmit motion by means of successive, engaged teeth.

GEAR RATIO - The ratio of the number of teeth on the larger gear to the number of teeth on the smaller gear.

HELICAL GEAR - Gears with the teeth cut at an angle to the axis of the gear.

HUB - The central part of a wheel or gear.

HYPOID GEAR - A gear that is similar in appearance to spiral bevel gear, but the teeth are cut so that the gears match in a position where the shaft centerlines do not meet.

PLANET GEARS - The gears in a planetary gear system that rotate around the sun gear.

PLANETARY GEARING - A system of gearing in which the gears are always in constant mesh and rotate about the central gear much like the planets rotate about the sun in the solar system.

RACE - A channel in the inner or outer ring of an anti-fraction bearing in which the balls or rollers roll.

RADIAL LOAD - A force perpendicular to the axis of rotation.

RING GEAR - This gear surrounds or rings the sun and planet gears in a planetary system.

SEMI-AUTOMATIC TRANSMISSION OR POWER SHIFT - A transmission in which gear changes are selected manually and are power actuated, no master clutch is involved.

SEPARATORS - A component in an anti-friction bearing which keeps the rolling components apart.

SLIDING-GEAR TRANSMISSION - A transmission in which gears are moved on their shafts to change gear ratios.

SPIRAL GEAR - A gear with teeth cut according to a mathematical curve on a cone. Spiral bevel gears that are not parallel have center lines that intersect.

SPLINE - Splines are multiple keys in the general form of internal and external gear teeth, used to prevent relative rotation of cylindrically fitted parts.

SPUR GEAR - Gears cut on a cylinder and the teeth are straight and parallel to the axis.

SUN GEAR - The central gear in a planetary gear system around which the rest of the gears rotate.

SYNCHRONIZE - To take place at the same time. In the case of gears, to cause to rotate at the same speed and in the same direction.

THRUST LOAD - A force parallel to the axis of rotation.

TRANSMISSION - The gears or system including the propeller shaft by which the power is transmitted from engine to the driven member.

VECTOR METHOD - A method by which the RPM and direction of rotation of the output member of a simple planetary system can be found if the input RPM and direction of rotation are known.

WORM GEAR - A gear with teeth that resemble a thread on a bolt. It is meshed with a gear that has teeth similar to a helical tooth except that it is dished to allow more contact.

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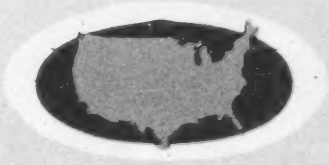

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